

SUPERCONDUCTING MATERIAL AND METHOD FOR PRODUCING THE SAME

FIELD OF THE INVENTION

The present invention relates to a superconducting
5 material, more particularly, a carbon Fullerene
superconducting material and a method for producing the same.

BACKGROUND OF THE INVENTION

Fullerene is a soccer-ball-shaped molecule which
10 consists of an arrangement of carbon atoms with a hollow
inside. As a conventional carbon Fullerene superconducting
material, alkali-doped C_{60} Fullerene molecules are known to
exert superconductivity. An oxide superconductor is also
known as a high-temperature superconducting material.

15 However, superconducting transition temperature of such
an alkali-doped C_{60} Fullerene molecule is as low as 40K at
maximum, rendering it unpractical for use under a relatively
high temperature. An oxide superconductor that exerts
superconductivity at the temperature of liquefied nitrogen is
20 poor in chemical stability and thus is not quite appropriate
to be used in an electric circuit material that requires fine
fabrication. Other superconducting material consisting of
carbon Fullerene molecules smaller than C_{60} molecules has not
been achieved.

25 Thus, the present invention has an objective of
providing a superconducting material in which C_{20} Fullerene
molecules are polymerized into a one-dimensional chain, where

bonding portions between C_{20} Fullerene molecules are bound via a SP^3 -bond form, or no sp^3 -bond is contained other than at the bonding portions between C_{20} Fullerene molecules, or where the superconducting material is obtained by injection
5 of electrons or positive holes.

SUMMARY OF THE INVENTION

In view of the above-described problems, the present invention is characterized by a superconducting material
10 comprising a structure wherein C_{20} Fullerene molecules are polymerized into a one-dimensional chain. The present invention is further characterized in that C_{20} Fullerene molecules are bound via sp^3 -bond, in that no sp^3 -bond exists other than the bonding portion between the C_{20} Fullerene
15 molecules or in that the superconducting material is obtained by injection of electrons or positive holes.

According to the present invention, C_{20} Fullerene having a stronger electron-lattice interaction than that of C_{60} Fullerene is employed. By polymerizing the C_{20} Fullerene
20 molecules into a one-dimensional chain in a porous material, and injecting electrons or positive holes into the obtained material, a superconductor with a transition temperature of the level of 100 K can be realized. The chemical stability of the superconducting material which C_{20} Fullerenes is
25 polymerized in the porous material is superior over that of the oxide superconductor. Accordingly, a superconducting

material with a higher superconducting transition temperature and higher chemical stability can be obtained.

BRIEF DESCRIPTION OF THE DRAWINGS

5 Figure 1A is a view showing chain structure of polymerized C_{20} Fullerene molecules bound via a single C-C covalent bond, and Figure 1B is a view showing chain structure of a double C-C covalent bond, respectively;

10 Figure 2A is a view showing distribution of π -electron orbits localized on C_{20} Fullerene molecules corresponding to the Figure 1A, and Figure 2B is a view showing distribution of π -electron orbits localized on C_{20} Fullerene molecules corresponding to the Figures 1B, respectively;

15 Figure 3 is a graph showing change in electric resistance of a one-dimensional C_{20} chain by temperature; and

 Figure 4 is a schematic view showing the chains of C_{20} Fullerene molecules in a porous material, generated through polymerization reaction.

20 DETAILED DESCRIPTION OF THE INVENTION

 Hereinafter, an embodiment of the present invention will be described with reference to the drawings.

25 In order to polymerize C_{20} Fullerene molecules into a one-dimensional chain, C_{20} is incorporated in a gap of a material having a large band gap between a valence band and a conduction band. Preferably, this material is a BN nanotube

or zeolite. Here, the BN nanotube is a tubular material that is formed from, instead of carbons, boron nitrides (BN) that are arranged in a stacked honeycomb layers. The BN nanotube have been available domestically and overseas since 1997 or
 5 around. To such a chain-form C_{20} Fullerene molecular polymer, electrons or positive holes are injected via an electric field application for phase transition to a superconductor. The method will be described below.

The C_{20} Fullerene molecule is a cage-shape molecule
 10 made up only of five-membered rings. These molecules can polymerize in a one-dimensional manner at an activation energy of 0.8 eV or less, as analyzed by the first-principle calculation. Figures 1A and 1B show two one-dimensional chain structures of different types of C_{20} Fullerene
 15 molecules. In Figure 1A, C_{20} Fullerene molecules made of carbon atoms 1 are bound to each other via a single C-C covalent bond 2. On the other hand, in Figure 1B, C_{20} Fullerene molecules made of carbon atoms 1 are bound to each other via a double C-C covalent bond 2. That is, there is
 20 two single C-C covalent bond between adjacent molecules. In both of the one-dimensional chain structures, each of the bonding portions between the C_{20} Fullerene molecules is bound via a single C-C bond with a bond length of 1.5 [angstrom], and a bond angle at the bonding portion approximating the
 25 bond angle of a diamond (about 105 [degree]). Thus, the C_{20} Fullerene molecules are bound via sp^3 -bond forming a regular tetrahedron while no sp^3 -bond can be found other than at the bonding portions between the C_{20} Fullerene molecules.

Due to this structure, in both of the one-dimensional chain structures shown in Figures 1A and 1B, wave functions (π -electrons) at the top of the valence band and the bottom of the conduction band of this material are localized only on the surfaces of the C_{20} Fullerenes separated from the bonding portions as shown in Figures 2A and 2B, respectively. The distributions of π -electron orbits 3 shown in Figures 2A and 2B correspond to the structures shown in Figures 1A and 1B, respectively. Due to this localization, the electrons and the positive holes are less likely to hop from one C_{20} Fullerene molecule to an adjacent C_{20} Fullerene molecule. Thus, dispersion of energy bands at the top of the valence band and the bottom of the conduction band can be small, thereby generating high state density. Thus, electrons or positive holes are doped to balance the energy levels of these bands with the Fermi level, thereby obtaining a metal state with high state density at Fermi level. Due to this high state density and strong electron-lattice interaction inside the C_{20} Fullerene molecules, the chain substance made of the C_{20} Fullerene molecules exerts superconductivity with a transition temperature in the order of 100 K.

According to the theoretical prediction by Devos and Lannoo (A. Devos and M. Lannoo, Phys. Rev. B, Vol. 58 (No. 13), p8236 (2000)), the electron-lattice interaction of C_{20} is about three times stronger than that of C_{60} . This can be explained by simple physics that the electron-lattice interaction is in inverse proportion to the number of carbon atoms contained in the Fullerene. On the other hand,

according to a simulation by the first-principle calculation, the doping amount has to be such that the number of electrons or positive holes per C_{20} Fullerene molecule is one or less.

Thus, the state density that can be achieved in the vicinity

5 of the Fermi level is about half the state density obtained with the C_{60} Fullerene molecule. According to the BCS

(Bardeen, Cooper, Schrieffer) theory of superconductivity, a superconducting transition temperature is in proportion to exponential of the product of the electron-lattice

10 interaction and the state density at the Fermi level.

Therefore, the transition temperature of C_{20} Fullerene molecule is $e^{3/2}$ times (about 4.5 times) higher than the superconducting transition temperature of C_{60} Fullerene molecule (40 K) and can be expected to be as large as 180 K

15 which is comparable to a transition temperature of a high-temperature superconducting material.

In view of the above-described consideration, Figure 3 shows the simulated results of a change in electric resistance by temperature. The resistance values are not

20 absolute values and are normalized such that the resistance at room temperature is 1. According to the first-principle calculation, when C_{20} Fullerene molecules are polymerized in a three-dimensional manner, they undergo phase transition and relax from a closed cage structure to an open structure.

25 Since such phase transition weakens the electron-lattice interaction, three-dimensional polymerization has to be avoided.

The above-mentioned chain substance can be produced according to the following procedure to avoid the undesirable three-dimensional polymerization. First C_{20} Fullerene molecules in a gas state are produced according to Prinzbach et al. (see Prinzbach et al., Nature (London), Vol. 407 (2000) p60). Then, using capillarity, the C_{20} Fullerene molecules are incorporated into a porous material having a large band gap between the valence band and the conduction band, such as zeolite or a BN nanotube. As a result, spontaneous polymerization reaction takes place at about room temperature, thereby producing a chain polymer 5 of C_{20} Fullerene molecules in the porous substance 4 as shown in Figure 4.

An electric field application technique is employed to inject electrons or positive holes in such a chain substance of C_{20} Fullerene molecules produced in the porous material. Since the chain of the C_{20} Fullerene molecules has filled in the voids that had existed in the porous material, there is no space for other molecule to fill in. Accordingly, the C_{20} Fullerene molecular chain is chemically stable. The entire sample is mounted on a silicon substrate that has been doped with boron (acceptor) at a high concentration, and applied with a strong electric field. Electrons are doped if the sample side is positive, while positive holes are doped if the sample side is negative. A silicon substrate doped with donors may also be used. In this case, however, the electric field has to be adjusted to control the doping amount.

By considering the stability according to the first-principle calculation, the superconducting transition temperature is at maximum when the number of doped electrons (or doped positive holes) per C_{20} Fullerene molecule is less than 1, and no superconductivity appears when the number is 1 or more. The electric structure according to the first-principle calculation shows that the effective potential difference between the C_{20} Fullerene chain substance and the silicon substrate needs to be controlled to be 0.5 eV or less.

According to the present invention, C_{20} Fullerene molecules having stronger electron-lattice interaction than that of C_{60} Fullerene molecules are used. By polymerizing this C_{20} Fullerene molecules into a one-dimensional chain in a porous substance, and injecting electrons or positive holes into the obtained porous material, a superconductor with a transition temperature of the level of 100 K can be realized. The chemical stability of the substance obtained by polymerizing C_{20} Fullerenes in the porous material is superior over that of an oxide superconducting material. Thus, a superconducting material having high superconducting transition temperature as well as excellent chemical stability can be obtained.

The invention may be embodied in other specific forms without departing from the spirit or essential characteristic thereof. The present embodiments is therefore to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims rather than by the foregoing description

and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein.

The entire disclosure of Japanese Patent Application No. 5 2000-390715 (filed on December 22, 2000) including specification, claims, drawings and summary are incorporated herein by reference in its entirety. The invention may be embodied in other specific forms without departing from the spirit or essential characteristic thereof.